

FORMULATION A DUAL EFFECT NATURAL DRAG REDUCTION AGENT

SITI NURAFFINI BINTI KAMARULIZAM

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ABSTRACT

Transporting liquids in pipelines is considered as one of the most economically feasible methods due to the controlled and safe media these liquids are transported within. The transportation of liquids through strategic pipelines and for hundreds of kilometers is also considered as one of the most power consuming sectors due to the turbulent mode these liquids are transported with. Additional supporting pumping station along the pipeline was one of the solutions applied, but its application added an additional cost to the total cost of transportation. The addition of polymeric additives to the main flow was proven to be a successful solution to the pumping power dissipation in pipelines due to the visco-elastic properties of these polymers that can suppress the turbulent structures inside the pipe. Most of these polymeric additives are not biodegradable and not environmentally friendly. In this present work, a new environmental friendly, soluble and insoluble Drag Reducing Agents (DRA) is introduced. These new additives are driven from plant and byproduct of tin industries which are okra mucilage from lady finger and slag particles. The drag reduction performances of the new additives were tested in water and hydrocarbon media. The water-soluble okra mucilage and the slag powder drag reduction performance were tested in water solution. To test the okra mucilage in hydrocarbon solution, the solubility of the original okra mucilage was changed using grafting co-polymerization technique. The objective of this research is to investigate the effect of this novel DRA based on classical parameters which are additive concentration, fluid velocity, internal pipe diameter and pipe length. Experimental closed loop circulation rig consisted of three different pipes diameter (0.0381m D.I, 0.0254m D.I and 0.0127m D.I) with 2.0m pipe length were setup in order to accomplish the objectives. The transported solution was flowing through pipelines from tank into required testing section for pressure drop determination. A ball valve located at recirculation pipes used to control the flow rate of solution entering testing section the flow meter sensor and pressure sensors located at each testing section will give reading at screen by SCADA software. From experimental results, highest Percentage Drag Reduction (%Dr) were obtained on 0.0381m D.I with 78% flowing through Re equal to 29017.44, 1000ppm and 0.5m pipe length for hydrocarbon liquid and 80% flowing through Re equal to 118235.42, 1000ppm and 0.5m for water as transported media. For slag particles analysis, highest %Dr was obtained on 0.0381m D.I with 70% flowing through Re equal to 29017.44, 1000ppm and 0.5m pipe length. While, for water, highest %Dr were obtained at 0.0381m D.I with 80% flowing through Re = 118235.42, 1000ppm and 0.5m pipe length. The fluid velocity effect give increment and decrement pattern depend on Re-%Dr relation curve. Increasing additive concentration and pipe diameter will increased the %Dr. The %Dr reading for the pipe length effects gives unnoticeable changes. However, it is predicted to decrease for polymeric DRA since the breakup of polymer when facing shear stress. Time consumption shows polymer are able to resist increment of pressure drop at certain period. However, suspended solid DRA show consistent %Dr reading with time consumption. A mathematical expression by using STATISTICA software was developed to delineate and verified the real mechanism of Drag Reduction (DR). As a conclusion, new greener DRA were successfully introduced and its effectiveness in improving the flow was proven experimentally.

ABSTRAK

Pengangkutan bendalir di dalam saluran paip dianggap sebagai salah satu kaedah yang terbaik dari segi ekonomi kerana bendalir berada dalam keadaan paling selamat dan terkawal. Walau bagaimanapun, pengangkutan bendalir melalui saluran paip sepanjang ratusan kilometer dianggap sebagai salah satu sektor yang menggunakan tenaga kuasa yang tinggi kerana aliran yang bergelora. Salah satu penyelesaian adalah dengan menambah stesen pam sokongan. Ini menyebabkan penambahan kos pengangkutan dan penyelenggaraan. Penambahan polimer ke dalam aliran utama telah terbukti menjadi satu penyelesaian yang berjaya kepada pembaziran tenaga kerana sifat likat-kenyal-polimer terbukti menyekat struktur bergelora di dalam paip. Walau bagaimanapun, kebanyakan bahan tambah polimer ini tidak boleh dilupuskan dan tidak mesra alam. Dalam kajian terbaru ini, Egen Pengurangan Seretan (DRA) yang mesra alam, (larut dan tidak larut) diperkenalkan. Bahan tambah ini (DRA) diperolehi dari lendir tumbuhan dan hasil sampingan industri timah. Prestasi pengurangan seretan telah diuji dalam media air dan hidrokarbon. Prestasi Pengurangan Seretan menggunakan lendir bendi dan serbuk sanga telah diuji di dalam larutan air. Untuk menguji lendir bendi dalam larutan hidrokarbon, keterlarutan lendir bendi yang asal telah diubah menggunakan teknik cantuman pempolimeran. Objektif kajian adalah untuk mengkaji kesan DRA berdasarkan parameter klasik iaitu kepekatan bahan tambah, halaju bendalir, diameter dalaman paip dan panjang paip. Pelantar gelung tertutup untuk menjalankan kajian terdiri daripada tiga paip berdiameter berbeza (0.0381m DI, 0.0254m DI dan 0.0127m DI) dengan panjang paip 2.0m adalah persediaan untuk mencapai objektif. Sebatian bendalir dan bahan tambah mengalir melalui saluran paip dari tangki ke bahagian ujian diperlukan untuk menentukan kejatuhan tekanan. Injap bola yang terletak di paip edaran semula yang digunakan untuk mengawal kadar aliran. Sebatian yang dikaji memasuki bahagian aliran bersensor tekanan yang terletak di setiap seksyen kajian akan memberi membaca di skrin dengan perisian SCADA. Daripada keputusan ujikaji, Peratus Pengurangan Seretan (%Dr) tertinggi telah diperolehi pada diameter paip 0.0381m DI dengan 78% yang mengalir melalui Re bersamaan dengan 29017.44, 1000ppm dan 0.5m panjang untuk bendalir hidrokarbon dan 80% yang mengalir melalui Re bersamaan dengan 118235.42, 1000ppm dan 0.5m untuk air sebagai media bendalir. Bagi analisis zarah sanga, %Dr tertinggi diperolehi pada 0.0381m DI dengan 70% yang mengalir melalui Re bersamaan dengan 29017.44, 1000ppm dan 0.5m panjang paip. Sementara itu, bagi air, %Dr tertinggi diperolehi di 0.0381m DI dengan 80% yang mengalir melalui Re bersamaan dengan 118235.42, 1000ppm dan 0.5m panjang paip. Kesan halaju bendalir memberi kenaikan dan penurunan corak bergantung kepada pola perhubungan Re-%Dr. Peningkatan kepekatan bahan tambah dan diameter paip akan meningkatkan % Dr. Keputusan %Dr untuk kesan panjang paip tidak memberi perubahan yang signifikan. Walau bagaimanapun, ia diramalkan berkurang kerana polimer DRA mengalami pemecahan polimer apabila menghadapi tegasan ricih. Penggunaan masa menunjukkan polimer mampu untuk menentang kejatuhan tekanan pada tempoh tertentu. Walau bagaimanapun, zarah tidak larut DRA menunjukkan bacaan %Dr yang konsisten dengan penggunaan masa. Ungkapan matematik dengan menggunakan perisian Statistica telah dibangunkan untuk menggambarkan dan mengesahkan mekanisme sebenar Pengurangan Drag (DR). Sebagai kesimpulan, DRA baru yang lebih hijau telah berjaya diperkenalkan dan terbukti dalam meningkatkan aliran.

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LIST OF SYMBOLS

m	meter
ppm	Part per million
ρ	Fluid density
I.D	Internal diameter
μ	Dynamic viscosity of fluid
h_f	Head loss due to friction
L	Pipe length
V	Average velocity
g	Acceleration due to gravity
f	Fanning friction factor
Δp	Pressure loss
τ_w	Wall shear stress
mL	Milliliter
μm	Micrometer
g	Gram
%Dr	Percentage drag reduction
C	Concentration
S	Siemens

LIST OF ABBREVIATIONS

Re	Reynolds Number
DRA	Drag Reducing Agent
DR	Drag Reduction
MW	Molecular weight
MDRA	Maximum drag reduction asymptote
IUPAC	International Union of Pure and Applied Chemistry
AN	Acrylonitrile
SEM	Scanning Electron Microscopy
I.D	Internal diameter
ΔL	Length difference
ΔP	Pressure Drop (Pressure Different)

CHAPTER 1

INTRODUCTION

1.1 STUDY BACKGROUND

Transporting liquids through pipelines is considered as one of the most energy-consuming sectors in the industry due to the turbulent mode these liquids are transported within. High energy consumption is essential in order to overcome the drag which opposes the flow movement inside piping system thus to maintain or increased fluid flow rate. Drag is identifiable as a mechanical force that exists and more accurately known as friction in the wall region that decreases velocity. The concept of drag reduction allows the pipelines to be operating at a lower pressure drop, thus reducing energy consumption and costs while transporting fluids through onshore and offshore pipelines, channels, cooling and heating devices, etc. The purpose of drag reduction study is to find a suitable means to reduce the physical force or drag that resists the movement of fluids through transporting an object.

The introduction of minute quantities of certain chemical additives is proven to have the ability to improve the flow inside pipelines carrying liquids in turbulent mode. However, these chemicals are harmful to the environment since it not biodegradable. A more environmentally friendly and biodegradable additive is needed.

In the present research work, two new types of drag reducing agents were introduced, which is a natural polymer that extracted from okra and slag particles, which are a byproduct of tin ingot manufacturing industry. These additives were tested as drag reducing agents for aqueous and hydrocarbon media flowing through a pipeline. An experimental rig was built to test the flow of refinery products and water in

pipelines. Classical variables such as the pipe diameter, pipe length, additive concentrations and the liquid flow rate were tested in the built closed-loop liquid circulation system with both introduced DRA.

1.2 PROBLEM STATEMENT

The addition of minute quantities of chemical additives to the main turbulent flow in pipelines carrying crude oil, refinery products or aqueous media, was a successful solution to the pumping power dissipation. Commercially, artificial visco-elastic polymeric additives are the most feasible additive with proven drag reduction efficiency when used in strategic pipelines. These additives acted successfully as flow improvers with minute addition concentrations. On the other hand, the polymeric drag reducing agents are not biodegradable and not environmentally friendly products. Usually the introduction of these additives will change the apparent physical properties of the transported liquid permanently because it is not a biodegradable polymer as mentioned earlier. An environmentally and biodegradable drag reducing agent is needed. In the present work, an approach towards this goal is introduced where a natural and biodegradable polymeric additive extracted from the okra pods is used as a flow improver in pipes carrying water in turbulent flow. Also, the natural polymer solubility will be changed by applying grafting technique to be hydrocarbon soluble additive to be used as a flow improver in hydrocarbon media.

The solubility of any chemical component in the transported media was a concrete condition for any material to be classified as a drag reducing agent which added more technical and financial difficulties in choosing the suitable additive for each application. Insoluble drag reducing agents can be considered as one of the solutions for such a problem. In the present work, insoluble drag reducing agent is introduced. This additive is in the powder form, and it is an industrial waste (slag powder) which adds another commercial value to the additive. The proposed insoluble additive can be used in both aqueous and hydrocarbon media without the need for any pre-treatment procedure.

1.3 RESEARCH OBJECTIVES

1. To introduce a new visco-elastic water soluble drag reducing agent (DRA) and hydrocarbon soluble drag reducing agent (DRA) from a grafted okra mucilage driven from okra plant (okra pod) and insoluble DRA which is slag particles (By-product of product of ore smelting in tin ingot production).
2. To test the drag reduction ability for both polymeric DRA and suspended solid DRA in both water and hydrocarbon media with classical parameters, which are flow rate, concentration, pipe length and pipe diameter and the effect of the proposed DRA on the rheological properties of the transported medias.
3. To develop a mathematical expression for friction factor (F) between experimental data and simulated data.

1.4 SCOPE OF RESEARCH

The scopes of this present study are described below:

- I. Preparation of mucilage from okra pod water as transported liquid.
- II. Preparation of hydrocarbon soluble mucilage by applying chemical grafting technique in diesel (gas-oil) as transported liquid.
- III. Preparation of suspended solid from ore smelting byproduct with 200 μ m particles size transporting in both pure water and diesel (gas-oil).
- IV. Testing the efficiency of DRA with concentration from 50ppm until 1000ppm for four testing section (0.5m, 1.0m, 1.5m, and 2.0m) and three different pipe diameter (0.0127m I.D, 0.0254m I.D, and 0.0381m I.D).

- V. Testing the drag reduction performance of the new additives using closed loop liquid circulation system with different flow rate for both media are same in certain range of flow according to internal pipe diameter. The flow rate for 0.0381m I.D is in the range from $7.5\text{m}^3/\text{h} - 11\text{m}^3/\text{h}$, for 0.0254m I.D is in the range from $5\text{m}^3/\text{h} - 8.5\text{m}^3/\text{h}$ and for 0.0127m I.D is in the range from $2.2\text{m}^3/\text{h} - 2.6\text{m}^3/\text{h}$.

1.5 OVERVIEW OF THE THESIS

This thesis consists of five main chapters including introduction in Chapter 1. The literatures related to drag reduction, surfactants, fiber suspensions and polymer are discussed in Chapter 2 while, the methodology, apparatus and equipment for experimental work are discussed in Chapter 3. In addition, the experimental results are discussed in Chapter 4 and the conclusion and recommendations are summarized in the last chapter, Chapter 5. This thesis is completed with references and appendices.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

When transporting liquids through strategic pipelines and for hundreds of kilometers, most of the pumping power is dissipated due to the turbulent mode of transportation. This is why a full understanding for the flow behaviors, modes and patterns in pipes are essential in any drag reduction investigation. A review of previous researchers and studies in the drag reduction field will be explained in this chapter, which including types of flow, type of drag reduction, mechanism involved and commercial application of DRA. The characteristic and differences of laminar and turbulent flow will be discussed as an introduction in sequence to study the drag reduction in the flow. Later, further sections will covered on types of drag reducing agents which include surfactants polymer, suspended solid and surfactant with the mechanism of the drag reduction, and the commercial applications in the drag reduction field.

2.2 DRAG REDUCTION

According to Compact Oxford Dictionary & Thesaurus Third Edition (Oxford Dictionaries, 2009), physical force that grips any movement of anything moves (fluid) is called 'drag'. From hydrodynamic connotation, drag can be identified as the force component applied on moving fluid in direction of the free stream which tends to isolate from the core stream in liquid's transportation through pipelines (Yunus and Cimbala, 2006).

(Lumley, 1969) definition of drag reduction was “Drag reduction is the reduction of skin friction in turbulent flow below that of the solvent”. Friction at the pipes' wall led to the further decrease of flows and tendency to form vortices is high due to friction that ‘hold’ liquid molecules at the buffer region which cause drag.

Drag reduction is associated with minimizing pumping power losses in transporting system. The main aims for drag reduction are to improve fluid-mechanical efficiency by using active agent known as drag reducing agents and to increase the flow performance by using the same amount of energy supplied (Mowla, and .Naderi, 2006). Therefore, minimizing the drag is essential in the relevant industries.

Percentage of drag reduction (%Dr) or the effectiveness of the drag reducing agent (DRA) can be defined as the ratio of reduction in the frictional pressure difference when the flow rates are held constant to the frictional pressure difference without DRA, and then multiplied by 100 as shown in equation 2.1 (Mowla et al., 2006).

$$\% Dr = \frac{(\Delta P_b - \Delta P_a)}{\Delta P_b} \times 100\% \quad (2.1)$$

A theory suggested by (Davidson, 2004) mentioned that turbulent spots occur where boundary-layer particles rotate, which means particles in the low boundary-layer move to higher positions and particles high in the boundary-layer move to lower positions.

2.3. DRAG REDUCTION AGENT (DRA)

DRA is any material that reduces frictional pressure during fluid flow in a conduit or pipeline. The addition of a small amount of DRA can result in important drag reduction effects in many types of flows (Azaiez, 2000). DRA allows increased in flow using the same amount of energy or decreased pressure drop for same flow rate of fluid in pipelines. DRA was found to suppress the disturbance structures which did not wrap around the entire pipe circumference (Al-Sarkhi and Hanratty, 2001).

Usually, DRA is injected at the center of pipeline during fully turbulent flow. DRA works by bursting the buffer zone, increase streaks (laminar sublayer) in pipeline, decrease vorticity force and increased velocity of flow without supplying extra energy.

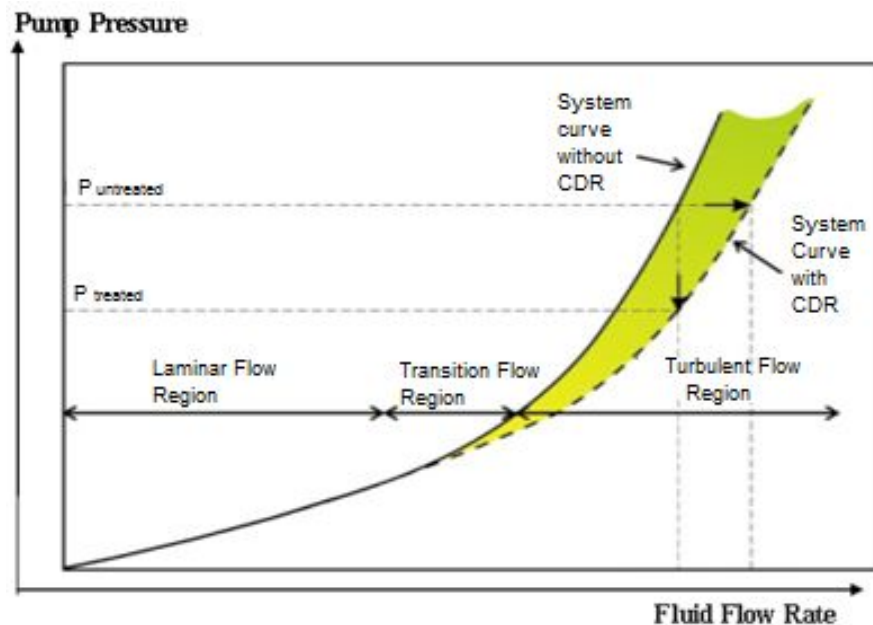


Figure 2.1: The effect of CDR (Chemical Drag Reducers) or DRA in pipelines to reduce pressure drop

Courtesy: King, 2002

Figure 2.1 show the effect of addition the drag reducing agent in the pipeline to reduce pressure drop. Pressure drop per unit length in the pipeline increases with the increase of fluid flow rate due to the wall friction and shear force. As the flow begin to tumble due to shearing, it will create transverse flow in which faster moving particle are transported into region of lower velocity and vice versa.

Polymers and surfactant micelles are the two main types of homogeneous drag reduction additives while heterogeneous drag reduction additives include solid phase fibers or gas phase micro bubbles (Kodama, 2002). These additive help to save the energy by reducing the recirculation effects (prevent liquids' molecules to rotate) that existed in turbulent flow. DRA can affect the solvent by changing viscosity. Fluid

elasticity in DRA also hinders the oscillation-induced streaming (Vlassopoulos and Schowalter, 1994).

Drag reduction has been applied to many flow situations with varying degrees of success such as hydraulic machinery, flow over submerged bodies, heating systems and jets (Abdelhamid et al., 2008). The first use of DRA in oil fields was to reduce pressure loss while pumping fluids down hole into fractured tight formations. Initially, %DR achieved was 80% in used of 600 ppm by weight in single phase flow (Vanko, 1997).

(Guissepina et al., 2011) had studied the influence of the addition of a drag reducing agent (100ppm PAA) to a pure liquid (water) in a stirred vessel. The vessel was stirred with two types of agitators, a Rushton turbine and an axial A310 impeller. This study had confirmed that the drag-reducing agent decreases power draw and increases mixing time.

2.3.1 Polymeric DRA

Polymeric DRA is proved to reduce transverse flow gradient, and then effectively creating flow with less turbulence intensity in the pipe. This phenomenon is usually occurring close to the pipe wall where axial flow velocity profile has a very steep gradient in which significant pressure losses happen (Stanford, 2005).

First reported drag reduction by polymeric additive was by Toms in 1946 when he accidentally discovered during his investigation on polymer mechanical degradation inside pipe flow apparatus. Dissolving a minute amount of long-chained polymer molecules in water, the frictional drag of turbulent flow could be reduced dramatically.

The most successful application of drag-reduction phenomenon has been in reducing the drag in crude oil transport through Trans Alaskan Pipelines (TAPS) and other pipelines in several countries (Hoyt, 1972). Within 10 years, effectiveness of the additives has increased up to 12 times from the earlier accomplishment in 1979.

(De Gennes, 1990) stated that polymeric drag reduction is due to elasticity rather than viscosity. However, polymer can be easily degraded and lost their effectiveness in turbulent flow in short period even it has high molecular weight ($>10^5$).

(Gadd, 1971) cited polymer additive is the resistance to elongation strain, resulting shear formation and bursting in near wall region which considered modern conception. (Min and Choi, 2005) also cited the elasticity of polymer is the most important properties to consider for potential drag reducing agent.

Polymeric DRA interact chemically by binding molecules of polymer and the solvents. (Massah and Hanratty, 1997) concluded polymer drag reduction could cause the changing in molecular structures of liquids that tend to produce Reynolds's stress. The Reynolds shear stress also strongly reduced, especially near the wall, and this is done by a polymer stress, which at maximum, drag has reduced about 40% of the total stress. These results have been compared with Laser Doppler Velocimetry (LDV) experiments (Ptasinski et al., 2001).

Polymers also can act in shelf-sheltering mechanism, which reducing the drag by decoupling solvent molecules in motions with polymer at the buffer region. (Ptasinski et al., 2003).

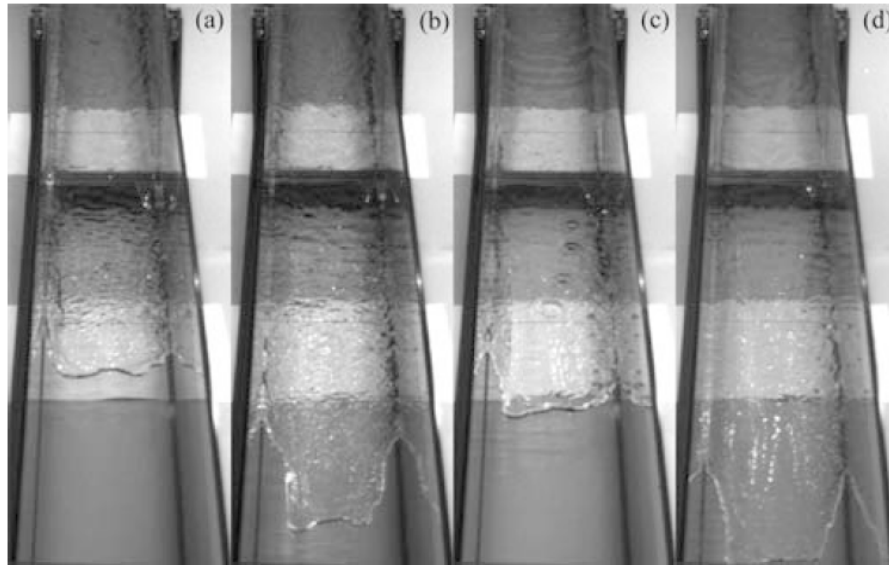


Figure 2.2: Differences between additions of PEO with 42 ppm at two different times.

A and B: Water without PEO at 0.63second and 0.8 second

C and D: Water with PEO at 0.63 second and 0.8 second

Courtesy: (Janosi et al., 2004)

(Janosi et al., 2004) investigated in dam break flows, where a finite volume of fluid is released from a compartment into a long, rectangular channel. The result reported drag reduction occurs in the presence of a minute amount of PEO (polyethylene oxide) in different time range. Figure 2.2 shows a picture taken for the PEO drag reduction behavior and it showed that the flow is much faster in the presence of PEO which one of the polymer chain which has high molecular weight.

Polymers are very effective as DRA but easily degraded due to the mechanical force from the pumps. The shear force of the pump will degrade the polymer mechanically (Sellin et al., 1982). The energy that rotating in the pump will break the linkage of polymer hence reduces its efficiency towards the solvent (Choi et al., 2000). The efficiency also will be reduced by vorticity stress in the turbulent flows, stressing or compressing stress in pump.